TOPEX/JASON COMBINED GPS/DORIS ORBIT DETERMINATION IN THE TANDEM PHASE

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ABSTRACT

In December 2001, the Jason-1 satellite was launched to extend the long-term success of the TOPEX/POSEIDON (T/P) oceanographic mission. The goals for the Jason-1 mission represent both a significant challenge and rare opportunity for precise orbit determination (POD) groups. Like its predecessor, Jason-1 carries three types of POD systems: a GPS receiver, a DORIS receiver and a laser retro-reflector. In view of the 1-cm goal for radial orbit accuracy, several major improvements have been made to the POD systems: 1) the GPS TurboRogue Space Receiver (TRSR) tracks up to 12 GPS spacecraft using advanced codeless tracking techniques; 2) a newly developed DORIS receiver can track two ground beacons simultaneously with lower noise. In addition, the satellite itself features more straightforward attitude behavior, and a symmetric shape, simplifying the orbit determination models compared to T/P. On the other hand, the area-to-mass ratio for Jason-1 is larger, implying larger potential surface-force errors. This paper will present Jason-1 POD results obtained at JPL using the Gipsy-Oasis II (GOA). Results from standard tests (orbit overlaps, Laser control points) suggest that 1 to 2 cm radial orbit precision is already being achieved using the JPL reduced-dynamic filter approach. New DORIS POD strategies will be an emphasis of this paper. These strategies make full profit of the additional number of common DORIS observations due to the T/P-Jason-1 tandem mode of orbit as well the additional dual-channel capability of the upgraded JASON receiver (allowing simultaneous tracking of two ground stations). New information on the satellite's time scale is availed through this new filtering strategy. Results show that a slight improvement could be gained on DORIS-based orbits using this strategy. This improvement may become more evident in the near future, as new launches will bring to 6 the total number of satellites collecting DORIS observations on the same day. Building on these results, we have extended the Gipsy/Oasis II software capability to more fully exploit the combined benefit of both GPS and DORIS measurements from T/P and Jason-1 in their preliminary tandem mode. POD test results will be used to demonstrate the accuracy of these orbits and to compare results in different cases: DORIS-alone, and GPS and DORIS together in both single- and multi-satellite modes. Finally, plans for future software enhancements, processing strategies and modeling improvements will be presented.

INTRODUCTION

On December 7, 2001, the US/France satellite JASON-1 has been launched as a follow-up mission of the highly successful TOPEX/POSEIDON satellite altimetry mission. Such missions have now a great impact on oceanographic sciences (Fu et al, 1994; Menard et al, 1995; Cazenave et al, 1999, Menard et al, 2000).

The accuracy of the estimated geophysical parameters is limited by the accuracy of the radar altimetry measurements as well as the orbital errors. In order to achieve a 2.5 cm accuracy or better, the JASON-1 satellite possesses 3 tracking devices: an improved DORIS receiver, a newly developed BlackJack GPS receiver and a Laser retro-reflectors. During the first 8 months of the mission, JASON-1 and TOPEX/POSEIDON have been flying in a tandem mode to insure continuity of the geophysical measurements as well as to provide an extended period of time for calibration and testing.

The goal of this paper is to present results in Precise Orbit Determination at JPL using the Gipsy/Oasis II software to process the JASON-1/DORIS data. In a second step, new filtering strategies that have been developed to accommodate DORIS data from all available satellites in the filter run, at the measurement level, will be presented. Finally, precise orbit determinations will also be presented using DORIS and GPS data simultaneously.

PROCESSING JASON/DORIS DATA ALONE

The JASON-1 DORIS receiver is part of a new generation of equipment and comprises several enhancement from the previous version on-board TOPEX/POSEIDON. The receiver is now digital and allows dual-stations simultaneous tracking using 2 channels (Sengenes et al, 2002). There was a significant increase in DORIS data measurements taken per day using this new type of receiver. Typically 7,800 DORIS data points are recorded for TOPEX while 11,700 are recorded for JASON during a 30-hour arc. This corresponds to an increase of almost 50% of data. This is a very significant improvement because unlike GPS, only 1 data per epoch could be recorded before that. The orbit determination was then more dependent on the accuracy of the physical models as less data could control them. With the additional channel, the increase is not 100% as it could be expected, because 2 DORIS stations cannot always be visible from the satellite due to the present network configuration (Fagard et al, 2002).

The DORIS receiver presents also a reduced signal-to-noise ratio of 0.3 mm/s that is effectively visible in the general data processing results. The typical daily DORIS postfit residuals obtained for 30-hour arcs for TOPEX have a mean value of 0.47 mm/s and 0.38 mm/s with JASON. This corresponds to a 20% improvement in DORIS residuals and can be attributed to the improved performances of the DORIS receiver and also a more compact shape of the satellite as well as a better definition of the attitude mode.

In this computation, we have fixed the reference frame to values that were kindly provided by J. Ries. ITRF-2000 coordinates were adopted when available (Boucher et al, 1996; Altamimi et al, 2002) using a fixed-network approach (Willis et al, 1994). For the more recent stations which could not appear in ITRF-2000, initial coordinates were derived using available DORIS data and standard plate tectonics velocities were adopted (Ries, 2002). Fortunately, only few stations were added to the network since the availability of the ITRF-2000 solution (Fagard et al, 2002).

PROCESSING TOPEX/DORIS AND JASON/DORIS DATA SIMULTANEOUSLY

Usually, in most analysis groups, precise orbits determinations are done on a mission-by-mission basis. Each satellite is processed independently of the others. Such a technique has several advantages: it provides an easy operational solution, it gives good and reliable results (Nouel et al, 1999) and finally it can even be used in real-time on-board the satellite (Jayles, 2002). However, it must be noted that such techniques are sub-optimal because they do not make full profit of all common parameters in the estimation. For example, internal parameters such as troposphere corrections or station clocks drifts are estimated per satellites independently and could lead to different estimates, as there is no cross-verification.

In the case of the TOPEX/JASON tandem phase, we have a unique long-term example of 2 satellites flying in a close formation mode, separated in time by 13 seconds. This new characteristic allows common tracking of 1 or 2 stations by the 2 satellites very frequently, JASON using its dual-channel capability while TOPEX is switching from 1 station to another sequentially.

Table 1 summarizes the list of common parameters that are not correctly treated in our newly developed multiple-satellite strategy.

Table 1. List of common parameters in a global DORIS adjustment

Parameter	Estimation
EOP	Once per day
troposphere	1/ 30 minutes + time constraints
Satellite clock	1 drift per 20 minutes
Station clock	1 drift per 20 minutes

Table 2. Available DORIS data at CDDIS, as Sep 30, 2002

Satellite	Available data in 2002
TOPEX	January 1 – August 31
JASON-1	January 15 – July 30
SPOT-2	January 1 – June 30
SPOT-4	January 1 – June 30
SPOT-5	June 11 – August 1
ENVISAT	April 25 – 30 + June 14 – August 28

It must be noted that the Gipsy/Oasis II software allows either stations and/or satellites clock drift estimates (Willis, 1996) and is not limited to 'station bias' per pass, as usually done by other analysis groups. In the case of 2 stations in common visibility of 2 satellites, we would only estimate 3 independent clock drift parameters (1 clock is used as reference). Other softwares would naturally estimate on the contrary 4 independent biases corresponding to the 4 existing passes. By estimating less parameters in a common satellite adjustment, we give more information to the models and we expect some gain in return in term of precision.

At least, such a strategy allowed us to detect a problem in the previously adopted DORIS data format that led to the establishment of the new 2.1 data format as the satellites clock corrections were not properly applied (Willis, 2002a). This problem could only be seen in the common mode adjustment were TOPEX and JASON were processed simultaneously and is now correctly solved for.

In fact, we have even enhanced the above described strategy (Willis, 2002) by using simultaneously all the available DORIS satellites and not only TOPEX and JASON. Table 2 summarizes the availability of the DORIS data at the CDDIS data center (Noll et al, 2002) and AVISO (for ENVISAT only), as at September 30, 2002. For the first 20 cycles of JASON for which we have conducted our study, from January 15 to July 30, 2002, there are almost always 4 satellites in common. After June 14, there are 6 DORIS satellites for a short period of time, as the SPOT-2 and SPOT-4 data are available with a longer delay and are not yet posted at CDDIS.

The daily overlaps residuals obtained for JASON either using JASON/DORIS only or using all available DORIS data are presently at the same level of precision (1.7 cm for JASON-only and 1.9 cm for all satellites for the radial component). Worst results in the multiple satellite case are obtained after July 1 and could indicate a possible problem in our ENVISAT/DORIS data processing. These data were released very recently and it is possible that all models may not be tuned correctly. Anyhow, there was no detectable increase in the postfit DORIS/JASON nor DORIS/TOPEX residuals when adding more satellites showing that such an approach could be performed and that our 'clock-modeling' approach is mathematically correct.

PROCESSING JASON/DORIS AND JASON/GPS DATA SIMULTANEOUSLY

Finally we have also upgraded the Gipsy/Oasis software to allow multi-technique data processing using simultaneously GPS and DORIS data in the same runs.

Table 3 describes in detail the estimation strategy that has been used in this GPS/DORIS data processing mode. A reduced dynamics has been adopted, giving more strength to the GPS and DORIS data and allowing for some small inaccuracy in general physical models (Bertiger et al, 1994; Yunck et al, 1994). Some parameters may still need to be tuned in the future. For example, the data weights are probably not too tight as usual postfit residuals give 27 cm for GPS pseudo-range, 5 mm for phase and 0.4 mm/s for DORIS Doppler in the case of JASON.

Table 3. Description of the GPS/DORIS JASON-1 data processing strategy at JPL

Data Weights	
GPS PRD	40 cm
GPS ϕ	1 cm
DORIS	0.4 mm/s
Physical Models	
Spacecraft models	CNES
Gravity Field	JGM-3
Atmospheric Drag	DTM-94
Estimation strategy	
Satellites state vector	6 per arc
Drag	1 per arc
1 cpr cross-track	colored noise (6-hr)
1cpr along-track	colored noise (6-hr)

The upgraded GPS BlackJack receiver performs extremely well on JASON and provides already almost cm accuracy orbits (Haines et al, 2002). Thus new type of GPS receiver is also embarked on-board the GRACE mission (Bertiger et al, 2002). Current GPS-only derived JASON orbits show radial precision of 7 mm in radial overlap (Haines et al, 2002). Our GPS/DORIS orbits shows a radial precision of 6 mm showing some slight improvement when adding the DORIS data in the orbit determination process.

In order to really test the accuracy of our GPS/DORIS orbits, we have used the 3rd technique on-board JASON as external control, as Laser points were not used at all in our estimation. Laser tracking stations coordinates were fixed to ITRF-2000 at the epoch of the measurements and the orbit was held fixed. Table 4 shows that the current agreement is typically at the 1 to 2 cm level.

Table 4. Description of the GPS/DORIS JASON-1 data processing strategy at JPL

Stations	*Mean (cm)*	*Std. Dev. (cm)*	*RMS (cm)*	*Min (cm)*	*Max (cm)*	*No of passes*
MacDonald (Texas)	+0.3	1.3	1.3	-2.0	+2.5	23
Monument (California)	+0.3	1.3	1.3	-2.0	+4.5	44
Greenbelt (Maryland)	+0.3	1.4	1.4	-2.6	+3.8	59
Haleakala (Hawaii)	+0.4	1.4	1.4	-2.8	+2.0	13
Yaragadee (Australia)	-0.2	1.4	1.4	-3.0	+3.2	57
Grasse (France)	-0.3	1.6	1.6	-4.2	+3.9	48
Hartebeestoech (S. Africa)	+0.2	1.7	1.7	-3.0	+3.4	26
ALL	+0.1	1.4	1.4	-4.2	+4.5	270

ANOMALOUS DORIS DATA IN THE SOUTH ATLANTIC ANOMALY REGION

However, it is important to note that all the DORIS results presented above were obtained without using the data from several tracking stations (Kourou, Arequipa, Ascencion, Cachoiera, Easter Island, Hartebeestoech, St Helena, Libreville and Santiago) for reasons that we will now explain.

Besides Precise Orbit Determination, DORIS data can also be used for ground location positioning. In this study, we have used all DORIS from all available satellites and processed them independently on a daily basis in a free-network approach (Willis, 1994). Results were then merged rigorously by satellites using the full covariance matrices to obtain weekly point positioning in ITRF-2000 for all DORIS beacons.

For all stations, weekly coordinates follow values and trends coherent with ITRF-2000 coordinates and velocities. However, for the some stations, and only for JASON solutions, the estimated station velocity is far from ITRF-2000 (by tens of cm!). For these stations, solutions coming form any other satellites except JASON are compatible with ITRF-2000 values. Table 5 summarizes the results obtained when comparing the apparent velocities of these stations, estimated using the first JASON 20 cycles, compared to ITRF-2000 used as reference.

Table 5. apparent displacement detected using the DORIS / JASON data

Acronym	*Station*	*Latitude*	*Longitude*	*N-Velocity (cm/y)*	*E-Velocity (cm/y)*	*V-Velocity (cm/y)*
KRUB	Kourou	5.1	307.4	-91 ± 5	46± 6	36 ± 4
AREB	Arequipa	-16.5	288.5	-30± 5	-8 ± 12	89.3 ± 7
ASDB	Ascencion	-7.9	345.7	-1 ± 7	-67 ± 15	113 ± 6
CACB	Cachoiera	-22.7	315.0	68 ± 8	-51 ± 11	116 ± 6
EASB	Easter Island	-27.1	250.6	28 ± 5	47 ± 7	27 ± 4
HBKB	Hartebeestoech	-25.9	27.7	25 ± 4	3 ± 4	-1 ± 3
HELB	St Helena	-15.9	354.3	72 ± 7	-12 ± 9	63 ± 6
LIBB	Libreville	0.4	9.7	-61 ± 6	-51 ± 13	64 ± 5
SANB	Santiago	-33.1	289.3	74 ± 5	24 ± 7	48 ± 5
	All others			< 10	< 10	< 10

It can be seen that for those stations, the estimated position drifts towards ITRF-2000 are significant and extremely distinct from the results from the other stations. This apparent has nothing to do with plate tectonic as such a velocity would cancel out in the difference between JASON-derived positions and ITRF-2000 positions. We should then expect such a drift to be very small and within the precision of the DORIS point positioning results.

For almost all stations, such a drift is neglectable (a few cm/year). However for 9 stations, all located in the South Atlantic Anomaly region, the drift is significant and in fact very large. In this region, around the coast of Brazil, due to the eccentric displacement of the earth Magnetic Field towards the Earth center of mass (by 450 km), the shielding effect of the magnetosphere presents a 'pot-hole'. Several authors have shown that oscillators in Low Earth Orbiting satellites are affected (Amstrong, 1992; Badhwar, 1999). In this region, for orbits of few hundred km of altitude and inclinaison comprised between 35 and 60 degree, the satellite is exposed to a higher particle flux when crossing this region. In order to get apparent stations velocities, the effect must be cumulative in time. The fact that stations in the North of the SAA tend to go South, that stations South of the SAA tend to go North can be explain by the fact that the satellite clock acceleration tends to attract the station but only when the satellite is in the SAA, making a disymetric behavior between the ascending and descending passes. The fact that the stations inside the SAA have a vertical apparent movement can also be explained by the same reason. In this case, the satellite is always in the SAA during the pass, so by symmetry, the apparent movement can only be in height.

Future JASON DORIS should help us better understand this problem. As the problem seems to increase in time, it should be easier to detect in DORIS residuals using more recent DORIS data in order to characterize this satellite clock acceleration inside the SAA region.

It must also be noted that none of the other DORIS satellites seem to be affected by this effect. Our present understanding is that the JASON satellite is one of the smallest one for which the protection of the on-board clock to radiations may not be as efficient.

However, for orbit computations only, one could argue that the data for those stations could still be kept as the effect of an erroneous coordinate of a unique station on the accuracy of the orbit is not so strong (Morel, 2002). In fact, even over the first 20 cycles (7 months), the DORIS postfit residuals grow regularly with time (from 0.38 mm/s to 0.45 mm/s) showing that the problem must not be ignored for precise orbit determination.

It is also possible that the effect could only be understood by using DORIS data in a raw format. Presently, DORIS data are preprocessed by CNES and the time tagging of the measurement is done using the pseudo-ranges over Toulouse and Kourou. As we now know that the satellite oscillator may not function correctly over Kourou, it is possible that this time-tagging may be slightly offset also.

CONCLUSIONS

In conclusion, the new tracking systems on board the JASON-1 satellite shows improvement for the DORIS new generation receiver as well as the BlackJack GPS receiver in term of better data noise and larger data availability. Precise DORIS orbits were generated using JASON/DORIS data, showing precision of about 1.7 cm using standard daily overlaps and similar accuracy using Laser data as external control.

We have also developed a new technique for processing multiple DORIS satellite in an optimized way making full profit of the common visibilities of TOPEX/POSEIDON and JASON-1 during the initial tandem phase, thanks to the highly evolutivity of the JPL Gipsy/Oasis II software. Preliminary results show very marginal improvement if any in terms of orbit accuracy. However, this technique should also helps us in the future in to provide better stations positions for Terrestrial Reference Frame maintenance and earth Rotation Parameters determination.

It must also be noted that the behavior of the JASON-1 DORIS on-board oscillator shows an anomalous behavior in the South Atlantic Anomaly region, leading to erroneous station positions estimations of several tens of cm. This phenomena seems to degrade linearly in time, at least during the first 20 first JASON cycles that were available for our investigation. Even if this effect is not totally understood it is probably linked to the change of frequency of the oscillator over this region due to specific magnetic field properties in this region.

Finally, reduced dynamics orbits were obtained for JASON-1 using simultaneously DORIS and GPS data in a common filter run. Those last results provide far better orbit repeatabilities of about 6 mm in the radial component. Tests conducted over the first 20 JASON cycles confirmed this results and show coherence at the 1 to 2 cm level with Laser points, used as external quality checks. The goal of 1cm radial accuracy for JASON-1 may not be now totally out of reach!

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